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(54) Abstract Title
Hydraulic actuating system for i.c. engine valves

(57) The system comprises:a hydraulic actuator (3) connected to the engine valve (6) which comprises a piston (7) sliding in a cylinder and defining with the cylinder a variable volume chamber (8); a source of pressurised hydraulic fluid (9); an exhaust for hydraulic fluid (10); a switching valve (11) connected to both of the source of pressurised hydraulic fluid (9) and the exhaust for hydraulic fluid (10); and a metering valve (2) connected between the switching valve (1) and the hydraulic actuator (3). The switching valve (1) controls direction of flow of hydraulic fluid to and from the hydraulic actuator (3) without controlling rate of flow of fluid therethrough and thereby controls whether the engine valve (6) is opened or closed by the hydraulic actuator (2). The metering valve (2) controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston (7) and hence speed of motion of the engine valve (6).

FIG. 1.

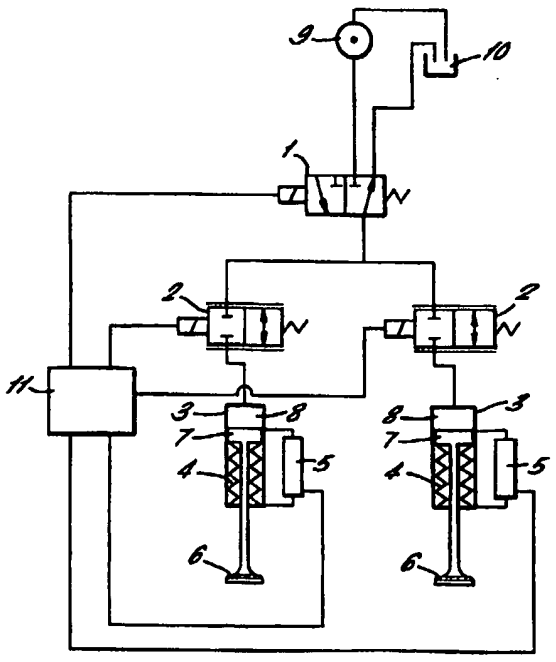

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FIG. 1.

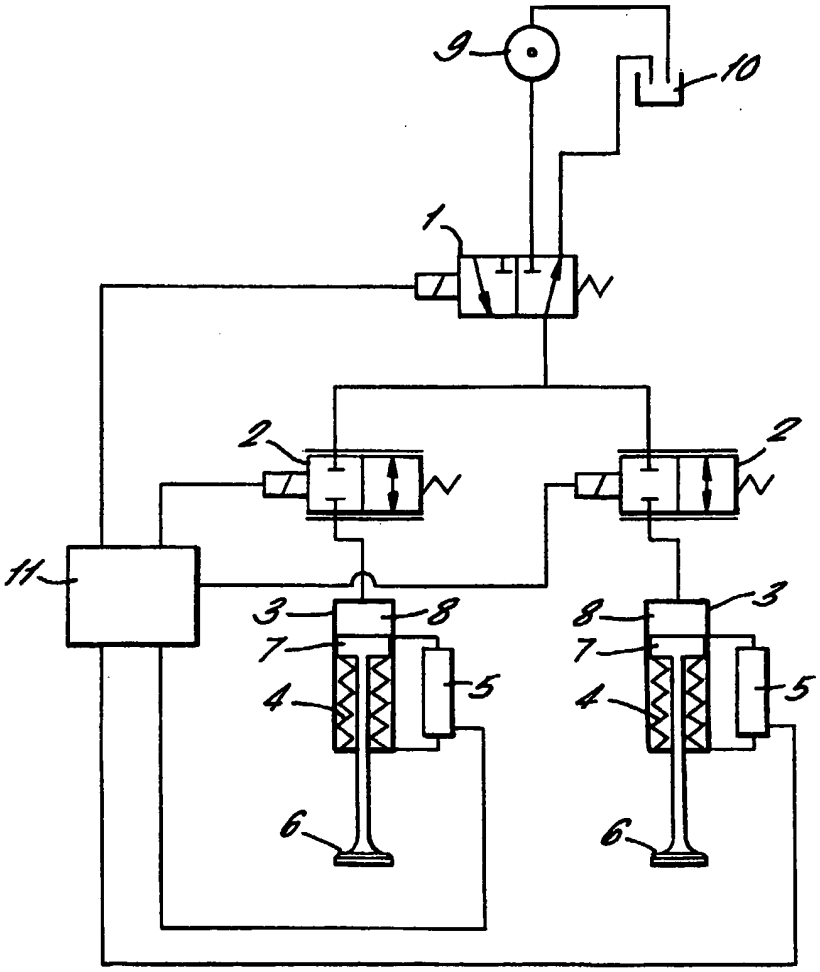
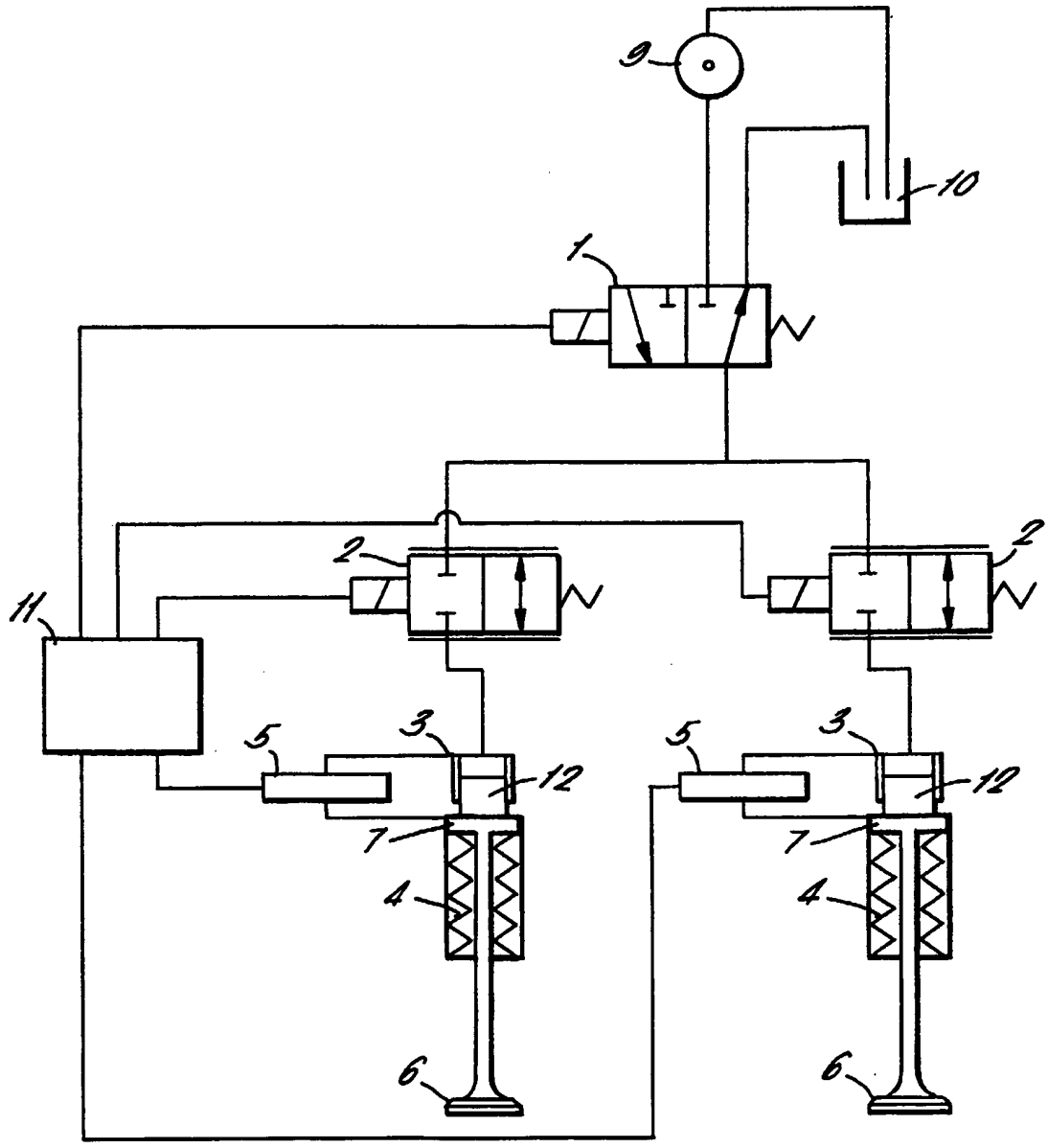


FIG. 2.



VALVE ACTUATING SYSTEM

The present invention relates to a valve actuating system which opens and closes an engine valve of an internal combustion engine.

Internal combustion engines have engine valves which control flow of gases into and out of each combustion chamber. An intake valve controls the flow of air or a mixture of fuel and air into the combustion chamber. An exhaust valve controls flow of combusted gases from the combustion chamber. These valves are typically poppet valves which are opened and closed by the action of a rotating cam shaft. The motion of each valve is set by the profile of a cam on the camshaft and does not vary with variations in speed or load. This is disadvantageous. The valve opening duration and valve lift preferable at low engine speeds is quite different from the valve opening duration and valve lift required at high speeds and loads.

More recently it has been proposed to replace mechanical camshafts with hydraulic actuators and systems have been proposed in which each engine valve is attached to a hydraulic actuator which opens and closes the valve. The hydraulic actuator is controlled by an electrical control system which can vary motion of the valve having regard to engine operating conditions such as speed and load.

To date, hydraulically actuated valves have not been commercially available in vehicles. A significant reason for this is the cost and complexity of a valve actuating system comprising such actuators. A

significant contributing factor to this is the cost of the spool valves which are required to control flow of hydraulic fluid to and from the hydraulic actuators. In a typical system, each hydraulic actuator is connected to a single spool valve, the spool valve in turn being connected to both a source of pressurised fluid and an exhaust for hydraulic fluid. Each spool valve controls whether fluid flows from the source of pressurised fluid to the hydraulic actuator or whether the fluid flows from the hydraulic actuator to the exhaust for hydraulic fluid. Each spool valve also controls the rate of flow of hydraulic fluid through the valve in order to control the motion of the controlled engine valve, and thereby how quickly the valve moves away from its valve seat during opening or how quickly the valve approaches its valve seat during closing.

The present invention, in a first aspect, provides a valve actuating system which opens and closes an engine valve of an internal combustion engine, the system comprising:

a hydraulic actuator connected to the engine valve which comprises a piston sliding in a cylinder and defining with the cylinder a variable volume chamber;

a source of pressurised hydraulic fluid;

an exhaust for hydraulic fluid;

a switching valve connected to both of the source of pressurised hydraulic fluid and the exhaust for hydraulic fluid; and

a metering valve connected between the switching valve and the hydraulic actuator; wherein:

the switching valve controls direction of flow of hydraulic fluid to and from the hydraulic actuator

without controlling rate of flow of fluid therethrough and thereby controls whether the engine valve is opened or closed by the hydraulic actuator; and

the metering valve controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston and thereby speed of motion of the engine valve.

In a second aspect the present invention provides a valve actuating system which opens and closes a pair of engine valves of an internal combustion engine, the system comprising:

a pair of hydraulic actuators connected one each to the pair of engine valves, each hydraulic actuator comprising a piston sliding in a cylinder and defining with the cylinder a variable volume chamber;

a source of pressurised hydraulic fluid;

an exhaust for hydraulic fluid;

a switching valve connected to both of the source of pressurised fluid and the exhaust for hydraulic fluid; and

a pair of metering valves connected one each to the pair of hydraulic actuators, the metering valves connecting the switching valve with the pair of hydraulic actuators; wherein:

the switching valve controls direction of flow of hydraulic fluid to and from the pair of hydraulic actuators without controlling rate of flow of fluid therethrough and thereby controls whether the pair of engine valves are opened or closed by the hydraulic actuators; and

each metering valve controls the rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston of the hydraulic actuator connected thereto and

hence speed of motion of the engine valve connected to the piston.

In the present invention, in both its aspects, the functions of flow direction control and of flow rate control have been separated and split between two separate valves. Each of the valves can be significantly cheaper and more robust than the spool valves of the prior art systems which each perform both functions of control of flow direction and also control of flow rate. A further advantage stems from response times, because a switching valve can be highly responsive, whereas a metering valve is typically less responsive. A spool valve which both meters flow as well as switching flow direction will have a slower reaction time than a switching valve. The applicant has realised that whilst it is important to quickly change flow direction, the flow rate of fluid can be varied more slowly without compromising overall control of the motion of an engine valve. Consequently, the splitting of the functions of flow direction and flow rate control between two separate valves has an advantage for the system overall.

Preferably, each switching valve has only two operating conditions:

a first operating condition in which the switching valve connects the source of pressurised fluid to each hydraulic actuator connected to the switching valve via the metering valve(s), whereby pressurised fluid can be supplied to the variable valve chamber of each hydraulic actuator to cause the piston thereof to move to open the engine valve; and

a second operating condition in which the switching valve connects the exhaust for hydraulic

fluid to each hydraulic actuator connected to the switching valve via the metering valve(s), whereby hydraulic fluid can be exhausted from the variable volume chamber of each hydraulic actuator and the piston allowed to move to close the engine valve.

The controlled engine valve can be an intake valve which controls induction of a charge of air or fuel/air mixture into a combustion chamber of the internal combustion engine. Alternatively, the controlled engine valve could be an exhaust valve controlling the exhaust of combusted gases from a combustion chamber of the internal combustion engine.

Preferably the switching valve is a three port, two-way digital switching valve. Such valves are relatively inexpensive but have a good frequency response.

Preferably each metering valve can stop the flow of hydraulic fluid therethrough and thereby stop motion of the piston of the hydraulic actuator connected thereto. This allows the possibility that where a pair of inlet valves are controlled by the valve actuating system of the second aspect of the invention, then one of the valves can be deactivated for instance at low speeds and low loads of the engine, whilst the other valve of the pair is still operated.

Preferably the switching valve is an electrically controlled valve, each metering valve is an electrically controlled valve, a transducer is associated with each hydraulic actuator and produces for the actuator an electrical signal indicating the

position of the piston relative to the cylinder and an electronic controller controls operation of the switching valve and operation of each metering valve and uses the signal(s) produced by the transducer(s) as feedback in a closed loop control arrangement.

Whilst the prior art systems have relied upon open loop control, the applicant has realised that this requires that each component in the valve actuating system is manufactured to a high tolerance and this inevitably drives up the cost of the valve actuating system. Instead, the present invention reduces the tolerance requirements for each component in the valve actuating system by using closed loop feedback control, with a position transducer indicating the position of piston in a hydraulic actuator relative to the surrounding cylinder. The feedback signal gives an indication of the position of the engine valve.

Preferably each hydraulic actuator comprises only one variable volume chamber for hydraulic fluid and spring means which acts on each piston to bias the piston to move to reduce in volume the variable volume chamber defined in part by the piston. The applicant proposes to use single-acting hydraulic actuators, again for reasons of reduced cost and complexity.

The present invention also relates to an internal combustion engine comprising a valve actuating system as described above.

Preferred embodiments of valve actuating system according to the present invention will now be described with reference to the accompanying figures

in which:

Figure 1 shows, in schematic form, a valve actuating system according to a first embodiment of the invention; and

Figure 2 shows, in schematic form, a valve actuating system according to a second embodiment of the invention.

In Figure 1 there can be seen a valve actuating system of a first embodiment of the invention. The system comprises a pair of poppet valves 6 of an internal combustion engine (not shown). In a preferred embodiment now described the pair of poppet valves 6 are intake valves of an internal combustion engine which control induction of a charge of fuel/air mixture into a combustion chamber (not shown) of the internal combustion engine. For reasons of simplicity, only a single pair of intake valves 6 are shown, but it should be appreciated that the internal combustion engine will most likely be a multi-cylinder engine, having a pair of intake valves for each cylinder of the engine.

Each engine valve 6 is connected directly to a piston 7 of a hydraulic actuator 3, each actuator 3 comprising a piston 7 movable in a cylinder. The pistons 7 define with their surrounding cylinders a pair of variable volume chambers 8. Each piston 7 is biassed by a spring 4 to move in a direction which would cause the piston 7 to reduce in volume the volume of the variable volume chamber 8. The bias applied on each piston 7 by a spring 4 acts to bias the engine valve 6 connected to the piston 7 in a closing direction, i.e. biases the engine valve 6 into a closed position in which the valve 6 rests in its

valve seat.

Each hydraulic actuator 3 is connected to a metering valve 2 individual to the actuator 3. Each metering valve 2 controls the flow of fluid into and out of the variable volume chamber 8 of the associated actuator 3.

The pair of metering valves 2 are both connected to a single switching valve 1. The switching valve 1 is a three port, two-way digital switching valve. The switching valve 1 is connected to a source of pressurised fluid 9 and to an exhaust for pressurised fluid 10. In the preferred embodiment, the source of pressurised fluid 9 is a pump powered by the internal combustion engine, the pump 9 drawing fluid from a sump 10 which is the exhaust for the hydraulic fluid.

The switching valve 1 can either connect both of the metering valves 2 to the source of pressurised fluid 9 or can connect both of the metering valves 2 to the exhaust for hydraulic fluid 10. The switching valve 1 does not in any way control the rate of flow through the valve, but only controls the flow direction. The switching valve 1 has a fast response time and switches quickly between its two operating conditions.

Each of the metering valves 2 is a proportional valve which controls the rate of flow of hydraulic fluid therethrough but which does not have any control on flow direction.

The switching valve 1 is an electrically controlled valve which is controlled by electrical

control signals generated by an electronic controller 11. Also the metering valves 2 are electrically controlled valves, again controlled by control signals produced by the electronic controller 11. Associated with each of the hydraulic actuators 3 is a position transducer 5 which senses the position of the piston 7 of an actuator relative to the cylinder surrounding the piston 7. The transducer 5 generates an electrical signal indicative of the position of the piston 7 and this electrical position signal is fed to the electronic controller 11 in a closed loop feedback control arrangement. In other words, the electronic controller 11 will issue control signals to the valves 1 and 2 which control the position of the piston 7 and the transducers 5 provide a feedback to the electronic control 11 so that the controller 11 can determine whether the pistons 7 reach the desired position required by the electronic controller 11.

When the electronic controller 11 wishes to open both of the intake valves 6 then it causes the switching valve 1 to switch to a position in which the source of pressurised fluid 9 is connected to the actuators 3 via the metering valves 2. Hydraulic fluid flows from the source of pressurised fluid 9 into the variable volume chambers 8 forcing the pistons 7 to move against the bias of the springs 4 and thereby to open the inlet valves 6. The rate of motion of the pistons 7 is controlled by the metering valves 2, again in response to control signals generated by the electronic controller 11.

When the electronic controller 11 wishes to close previously opened engine valves 6 then it controls operation of switching valve 1 so that the switching

valve 1 connects both of the actuators 3 to the sump 10 via the metering valve 2. Therefore, the pistons 7 can move under the bias of the springs 4 to expel hydraulic fluid from the variable volume chambers 8 out to the sump 10. The rate of flow of hydraulic fluid from the variable volume chambers 8 is controlled by the metering valves 2 so that the speed of motion of each piston 7 is controlled.

It is possible that the pair of intake valves 6 are controlled to have exactly the same motion. Alternatively, the two valves can be controlled to have different motions. For instance, at low engine speeds and low loads, one of the metering valves 2 can stop flow of hydraulic fluid therethrough and therefore stop operation of the associated engine valve 6. Thus, the system can provide for valve deactivation.

At any time each metering valve 2 can stop flow of fluid therethrough in order to hold an associated engine valve 6 in a fixed position.

It is envisaged that the pump 9 will supply hydraulic fluid at a pressure of roughly 80 bar. Typically, a filter will be included in the hydraulic system somewhere to filter out any particles of a size larger than 25 microns.

In Figure 2 there can be seen a valve actuating system of a second embodiment of the invention. The second embodiment is in many ways identical to the first embodiment and identical components are given identical reference numerals. The second embodiment works in the same way as the first embodiment and thus

the mode of operation will also not be described. Instead only the differences between the two embodiments will be described.

In the second embodiment the poppet valves 6 are not integrally formed with the actuators 3. Instead each actuator 3 has a piston 12 which abuts the top of a poppet valve 7 This eases manufacture since it is not necessary for the poppet valve 6 to be exactly aligned with the axis of the cylinder of the actuator 3.

In the second embodiment the displacement transducers 5 measure the positions of the pistons 12 (and measure actuator motion) rather than the positions of the poppet valves 6.

Each metering valve 2 could be integrated with the actuator 3 associated therewith in the manner described in UK Patent Application No.0100632.9. In the arrangement described in the application No.0100632.9 a metering valve, a single actuator and a position sensor are integrated in a single compact package and a normal engine valve spring is used as the biassing spring, the engine valve spring biassing the poppet valve into abutment with an abutment surface on a member linked to the piston in the hydraulic actuator.

Whilst above the valve actuating systems are described controlling the motion of a pair of inlet valves, the system could also be used to control the motion of a pair of exhaust valves. Whilst the above valve actuating systems are described controlling the motion of a pair of valves for a single cylinder, it should be appreciated that in a multi-cylinder engine the single controller 11 will control a plurality of

pairs of poppet valves, each pair having its own set of two metering valves 2 and switching valve 1.

Whilst described above a pair of poppet valves 6 are together connected to a single switching valve 1, if the systems are used in an engine which has only one exhaust valve and inlet valve per cylinder, then each poppet valve 6 would be controlled on its own by a set of electro-hydraulic control valves comprising a single metering valve 2 individual to the poppet valve 6 and a single switching valve 1 individual to the poppet valve 6.

Whilst above the controlled valves 6 have been inlet and exhaust valves, they could be other types of valve, e.g. exhaust gas recirculation control valves or other gas exchange valves.

The present invention provides complete control over the position of an engine valve. This is done by using closed loop position feedback. By providing a feedback signal the system can take account of imperfections and the component parts do not have to be manufactured to high tolerances.

If combined metering valves and actuators such as described in UK Patent Application No.0100632.9 are employed then control is enhanced because the bulk modulus of the fluid in the variable volume chamber and the pipe connecting the variable volume chamber to the metering valve is reduced to a minimum. This reduces hysteresis losses and gives more exact control.

CLAIMS

1. A valve actuating system which opens and closes an engine valve of an internal combustion engine, the system comprising:

a hydraulic actuator connected to the engine valve which comprises a piston sliding in a cylinder and defining with the cylinder a variable volume chamber;

a source of pressurised hydraulic fluid;

an exhaust for hydraulic fluid;

a switching valve connected to both of the source of pressurised hydraulic fluid and the exhaust for hydraulic fluid; and

a metering valve connected between the switching valve and the hydraulic actuator; wherein:

the switching valve controls direction of flow of hydraulic fluid to and from the hydraulic actuator without controlling rate of flow of fluid therethrough and thereby controls whether the engine valve is opened or closed by the hydraulic actuator; and

the metering valve controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston and hence speed of motion of the engine valve.

2. A valve actuating system which opens and closes a pair of engine valves of an internal combustion engine, the system comprising:

a pair of hydraulic actuators connected one each to the pair of engine valves, each hydraulic actuator comprising a piston sliding in a cylinder and defining with the cylinder a variable volume chamber;

a source of pressurised hydraulic fluid;

an exhaust for hydraulic fluid;

a switching valve connected to both of the source of pressurised fluid and the exhaust for hydraulic fluid; and

a pair of metering valves connected one each to the pair of hydraulic actuators, the metering valves connecting the switching valve with the pair of hydraulic actuators; wherein:

the switching valve controls direction of flow of hydraulic fluid to and from the pair of hydraulic actuators without controlling rate of flow of fluid therethrough and thereby controls whether the pair of engine valves are opened or closed by the hydraulic actuators; and

each metering valve controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston of the hydraulic actuator connected thereto and hence speed of motion of the engine valve connected to the piston.

3. A valve actuating system as claimed in claim 1 or claim 2 wherein each engine valve has only two operating conditions:

a first operating condition in which the switching valve connects the source of pressurised fluid to each hydraulic actuator connected to the switching valve via the metering valve(s), whereby pressurised fluid can be supplied to the variable volume chamber of each hydraulic actuator to cause the piston thereof to move to open the engine valve; and

a second operating condition in which the switching valve connects the exhaust for hydraulic fluid to each hydraulic actuator connected to the switching valve via the metering valve(s), whereby hydraulic fluid can be exhausted from the variable volume chamber of each hydraulic actuator and the

piston allowed to move to close the engine valve.

4. A valve actuating system as claimed in any one of the preceding claims, wherein each engine valve is an intake valve controlling the induction of a charge of air or fuel/air mixture into a combustion chamber of the internal combustion engine.

5. A valve actuating system as claimed in any one of claims 1 to 3 wherein each engine valve is an exhaust valve controlling the exhaust of combusted gases from a combustion chamber of the internal combustion engine.

6. A valve actuating system as claimed in any one of the preceding claims wherein the switching valve is a three port, two-way, digital switching valve.

7. A valve actuating system as claimed in any one of the preceding claims in which each metering valve can stop flow of hydraulic fluid therethrough and thereby stop motion of the piston of the hydraulic actuator connected thereto.

8. A valve actuating system as claimed in any one of the preceding claims wherein the switching valve is an electrically controlled valve; each metering valve is an electrically controlled valve; a transducer is associated with each hydraulic actuator and produces for the actuator an electrical signal indicating position of the piston relative to the cylinder; and an electronic controller controls operation of the switching valve and operation of each metering valve and uses the signal(s) produced by the transducer(s)

as feedback in a closed loop control arrangement.

9. A valve actuating system as claimed in any one of the preceding claims wherein each hydraulic actuator comprises only one variable volume chamber for hydraulic fluid and spring means which acts on each piston to bias the piston to move to reduce in volume the variable volume chamber defined in part by the piston.

10. An internal combustion engine comprising a valve actuating system as claimed in any one of the preceding claims.

11. A valve actuating system substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

: 278277: AWP: CTF: LONDOCS

17

Application No:	GB 0108055.5	**Examiner:**	John Twin
Claims searched:	1 to 15	**Date of search:**	23 May 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): F1B (B2P5, BB130)

Int Cl (Ed.7): F01L 9/00, 9/02, 9/04

Other: online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 6024060 (Buehrle et al.)	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Hydraulic actuating system for i.c. engine valves

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Bibliographische Daten

The system comprises:a hydraulic actuator (3) connected to the engine valve (6) which comprises a piston (7) sliding in a cylinder and defining with the cylinder a variable volume chamber (8); a source of pressurised hydraulic fluid (9); an exhaust for hydraulic fluid (10); a switching valve (11) connected to both of the source of pressurised hydraulic fluid (9) and the exhaust for hydraulic fluid (10); and a metering valve (2) connected between the switching valve (1) and the hydraulic actuator (3). The switching valve (1) controls direction of flow of hydraulic fluid to and from the hydraulic actuator (3) without controlling rate of flow of fluid therethrough and thereby controls whether the engine valve (6) is opened or closed by the hydraulic actuator (2). The metering valve (2) controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston (7) and hence speed of motion of the engine valve (6).

Beschreibung

VALVE ACTUATING SYSTEM

The present invention relates to a valve actuating system which opens and closes an engine valve of an internal combustion engine.

Internal combustion engines have engine valves which control flow of gases into and out of each combustion chamber. An intake valve controls the flow of air or a mixture of fuel and air into the combustion chamber. An exhaust valve controls flow of combusted gases from the combustion chamber. These valves are typically poppet valves which are opened and closed by the action of a rotating cam shaft. The motion of each valve is set by the profile of a cam on the camshaft and does not vary with variations in speed or load. This is disadvantageous. The valve opening duration and valve lift preferable at low engine speeds is quite different from the valve opening duration and valve lift required at high speeds and loads.

More recently it has been proposed to replace mechanical camshafts with hydraulic actuators and systems have been proposed in which each engine valve is attached to a hydraulic actuator which opens and closes the valve. The hydraulic actuator is controlled by an electrical control system which can vary motion of the valve having regard to engine operating conditions such as speed and load.

To date, hydraulically actuated valves have not been commercially available in vehicles. A significant reason for this is the cost and complexity of a valve actuating system comprising such actuators. A significant contributing factor to this is the cost of the spool valves which are required to control flow of hydraulic fluid to and from the hydraulic actuators.

In a typical system, each hydraulic actuator is connected to a single spool valve, the spool valve in turn being connected to both a source of pressurised fluid and an exhaust for hydraulic fluid. Each spool valve controls whether fluid flows from the source of pressurised fluid to the hydraulic actuator or whether the fluid flows from the hydraulic actuator to the exhaust for hydraulic fluid. Each spool valve also controls the rate of flow of hydraulic fluid through the valve in order to control the motion of the controlled engine valve, and thereby how

quickly the valve moves away from its valve seat during opening or how quickly the valve approaches its valve seat during closing.

The present invention, in a first aspect, provides a valve actuating system which opens and closes an engine valve of an internal combustion engine, the system comprising: a hydraulic actuator connected to the engine valve which comprises a piston sliding in a cylinder and defining with the cylinder a variable volume chamber; a source of pressurised hydraulic fluid; an exhaust for hydraulic fluid; a switching valve connected to both of the source of pressurised hydraulic fluid and the exhaust for hydraulic fluid; and a metering valve connected between the switching valve and the hydraulic actuator; wherein: the switching valve controls direction of flow of hydraulic fluid to and from the hydraulic actuator without controlling rate of flow of fluid therethrough and thereby controls whether the engine valve is opened or closed by the hydraulic actuator; and the metering valve controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston and thereby speed of motion of the engine valve.

In a second aspect the present invention provides a valve actuating system which opens and closes a pair of engine valves of an internal combustion engine, the system comprising: a pair of hydraulic actuators connected one each to the pair of engine valves, each hydraulic actuator comprising a piston sliding in a cylinder and defining with the cylinder a variable volume chamber; a source of pressurised hydraulic fluid; an exhaust for hydraulic fluid; a switching valve connected to both of the source of pressurised fluid and the exhaust for hydraulic fluid; and a pair of metering valves connected one each to the pair of hydraulic actuators, the metering valves connecting the switching valve with the pair of hydraulic actuators; wherein: the switching valve controls direction of flow of hydraulic fluid to and from the pair of hydraulic actuators without controlling rate of flow of fluid therethrough and thereby controls whether the pair of engine valves are opened or closed by the hydraulic actuators; and each metering valve controls the rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston of the hydraulic actuator connected thereto and hence speed of motion of the engine valve connected to the piston.

In the present invention, in both its aspects, the functions of flow direction control and of flow rate control have been separated and split between two separate valves. Each of the valves can be significantly cheaper and more robust than the spool valves of the prior art systems which each perform both functions of control of flow direction and also control of flow rate. A further advantage stems from response times, because a switching valve can be highly responsive, whereas a metering valve is typically less responsive. A spool valve which both meters flow as well as switching flow direction will have a slower reaction time than a switching valve.

The applicant has realised that whilst it is important to quickly change flow direction, the flow rate of fluid can be varied more slowly without compromising overall control of the motion of an engine valve.

Consequently, the splitting of the functions of flow direction and flow rate control between two separate valves has an advantage for the system overall.

Preferably, each switching valve has only two operating conditions: a first operating condition in which the switching valve connects the source of pressurised fluid to each hydraulic actuator connected to the switching valve via the metering valve (s), whereby pressurised fluid can be supplied to the variable valve chamber of each hydraulic actuator to cause the piston thereof to move to open the engine valve; and a second operating condition in which the switching valve connects the exhaust for hydraulic fluid to each hydraulic actuator connected to the switching valve via the metering valve (s), whereby hydraulic fluid can be exhausted from the variable volume chamber of each hydraulic actuator and the piston allowed to move to close the engine valve.

The controlled engine valve can be an intake valve which controls induction of a charge of air or fuel/air mixture into a combustion chamber of the internal combustion engine. Alternatively, the controlled engine valve could be an exhaust valve controlling the exhaust of combusted gases from a combustion chamber of the internal combustion engine.

Preferably the switching valve is a three port, two-way digital switching valve. Such valves are relatively inexpensive but have a good frequency response.

Preferably each metering valve can stop the flow of hydraulic fluid therethrough and thereby stop motion of the piston of the hydraulic actuator connected thereto. This allows the possibility that where a pair of inlet valves are controlled by the valve actuating system of the second aspect of the invention, then one of the valves can be deactivated for instance at low speeds and low loads of the engine, whilst the other valve of the pair is still operated.

Preferably the switching valve is an electrically controlled valve, each metering valve is an electrically controlled valve, a transducer is associated with each hydraulic actuator and produces for the actuator an electrical signal indicating the position of the piston relative to the cylinder and an electronic controller controls operation of the switching valve and operation of each metering valve and uses the signal (s) produced by the transducer (s) as feedback in a closed loop control arrangement.

Whilst the prior art systems have relied upon open loop control, the applicant has realised that this requires that each component in the valve actuating system is manufactured to a high tolerance and this inevitably drives up the cost of the valve actuating system. Instead, the present invention reduces the tolerance requirements for each component in the valve actuating system by using closed loop feedback control, with a position transducer indicating the position of piston in a hydraulic actuator relative to the surrounding cylinder. The feedback signal gives an indication of the position of the engine valve.

Preferably each hydraulic actuator comprises only one variable volume chamber for hydraulic fluid and spring means which acts on each piston to bias the piston to move to reduce in volume the variable volume chamber defined in part by the piston. The applicant proposes to use single-acting hydraulic actuators, again for reasons of reduced cost and complexity.

The present invention also relates to an internal combustion engine comprising a valve actuating system as described above.

Preferred embodiments of valve actuating system according to the present invention will now be described with reference to the accompanying figures in which :
Figure 1 shows, in schematic form, a valve actuating system according to a first embodiment of the invention ; and
Figure 2 shows, in schematic form, a valve actuating system according to a second embodiment of the invention.

In Figure 1 there can be seen a valve actuating system of a first embodiment of the invention. The system comprises a pair of poppet valves 6 of an internal combustion engine (not shown). In a preferred embodiment now described the pair of poppet valves 6 are intake valves of an internal combustion engine which control induction of a charge of fuel/air mixture into a combustion chamber (not shown) of the internal combustion engine. For reasons of simplicity, only a single pair of intake valves 6 are shown, but it should be appreciated that the internal combustion engine will most likely be a multi-cylinder engine, having a pair of intake valves for each cylinder of the engine.

Each engine valve 6 is connected directly to a piston 7 of a hydraulic actuator 3, each actuator 3 comprising a piston 7 movable in a cylinder. The pistons 7 define with their surrounding cylinders a pair of variable volume chambers 8. Each piston 7 is biassed by a spring 4 to move in a direction which would cause the piston 7 to reduce in volume the volume of the variable volume chamber 8. The bias applied on each piston 7 by a spring 4 acts to bias the engine valve 6 connected to the piston 7 in a closing direction, i. e. biases the engine valve 6 into a closed position in which the valve 6 rests in its valve seat.

Each hydraulic actuator 3 is connected to a metering valve 2 individual to the actuator 3. Each metering valve 2 controls the flow of fluid into and out of the variable volume chamber 8 of the associated actuator 3.

The pair of metering valves 2 are both connected to a single switching valve 1. The switching valve 1 is a three port, two-way digital switching valve. The switching valve 1 is connected to a source of pressurised fluid 9 and to an exhaust for pressurised fluid 10. In the preferred embodiment, the source of pressurised fluid 9 is a pump powered by the internal combustion engine, the pump 9 drawing fluid from a sump 10 which is the exhaust for the hydraulic fluid.

The switching valve 1 can either connect both of the metering valves 2 to the source of pressurised fluid 9 or can connect both of the metering valves 2 to the exhaust for hydraulic fluid 10. The switching valve 1 does not in any way control the rate of flow through the valve, but only controls the flow direction. The switching valve 1 has a fast response time and switches quickly between its two operating conditions.

Each of the metering valves 2 is a proportional valve which controls the rate of flow of hydraulic fluid therethrough but which does not have any control on flow direction.

The switching valve 1 is an electrically controlled valve which is controlled by electrical control signals generated by an electronic controller 11. Also the metering valves 2 are electrically controlled valves, again controlled by control signals produced by the electronic controller 11. Associated with each of the hydraulic actuators 3 is a position transducer 5 which senses the position of the piston 7 of an actuator relative to the

cylinder surrounding the piston 7. The transducer 5 generates an electrical signal indicative of the position of the piston 7 and this electrical position signal is fed to the electronic controller 11 in a closed loop feedback control arrangement. In other words, the electronic controller 11 will issue control signals to the valves 1 and 2 which control the position of the piston 7 and the transducers 5 provide a feedback to the electronic control 11 so that the controller 11 can determine whether the pistons 7 reach the desired position required by the electronic controller 11.

When the electronic controller 11 wishes to open both of the intake valves 6 then it causes the switching valve 1 to switch to a position in which the source of pressurised fluid 9 is connected to the actuators 3 via the metering valves 2. Hydraulic fluid flows from the source of pressurised fluid 9 into the variable volume chambers 8 forcing the pistons 7 to move against the bias of the springs 4 and thereby to open the inlet valves 6. The rate of motion of the pistons 7 is controlled by the metering valves 2, again in response to control signals generated by the electronic controller 11.

When the electronic controller 11 wishes to close previously opened engine valves 6 then it controls operation of switching valve 1 so that the switching valve 1 connects both of the actuators 3 to the sump 10 via the metering valve 2. Therefore, the pistons 7 can move under the bias of the springs 4 to expel hydraulic fluid from the variable volume chambers 8 out to the sump 10. The rate of flow of hydraulic fluid from the variable volume chambers 8 is controlled by the metering valves 2 so that the speed of motion of each piston 7 is controlled.

It is possible that the pair of intake valves 6 are controlled to have exactly the same motion.

Alternatively, the two valves can be controlled to have different motions. For instance, at low engine speeds and low loads, one of the metering valves 2 can stop flow of hydraulic fluid therethrough and therefore stop operation of the associated engine valve 6. Thus, the system can provide for valve deactivation.

At any time each metering valve 2 can stop flow of fluid therethrough in order to hold an associated engine valve 6 in a fixed position.

It is envisaged that the pump 9 will supply hydraulic fluid at a pressure of roughly 80 bar.

Typically, a filter will be included in the hydraulic system somewhere to filter out any particles of a size larger than 25 microns.

In Figure 2 there can be seen a valve actuating system of a second embodiment of the invention. The second embodiment is in many ways identical to the first embodiment and identical components are given identical reference numerals. The second embodiment works in the same way as the first embodiment and thus the mode of operation will also not be described.Instead only the differences between the twoembodiments will be described.

In the second embodiment the poppet valves 6 are not integrally formed with the actuators 3. Instead each actuator 3 has a piston 12 which abuts the top of a poppet valve 7 This eases manufacture since it is not necessary for the poppet valve 6 to be exactly aligned with the axis of the cylinder of the actuator 3.

In the second embodiment the displacement transducers 5 measure the positions of the pistons 12 (and measure actuator motion) rather than the positions of the poppet valves 6.

Each metering valve 2 could be integrated with the actuator 3 associated therewith in the manner described in UK Patent Application No. 0100632.9. In the arrangement described in the application
No. 0100632.9 a metering valve, a single actuator and a position sensor are integrated in a single compact package and a normal engine valve spring is used as the biassing spring, the engine valve spring biassing the poppet valve into abutment with an abutment surface on a member linked to the piston in the hydraulic actuator.

Whilst above the valve actuating systems are described controlling the motion of a pair of inlet valves, the system could also be used to control the motion of a pair of exhaust valves. Whilst the above valve actuating systems are described controlling the motion of a pair of valves for a single cylinder, it should be appreciated that in a multi-cylinder engine the single controller 11 will control a plurality of pairs of poppet valves, each pair having its own set of two metering valves 2 and switching valve 1.

Whilst described above a pair of poppet valves 6 are together connected to a single switching valve 1, if the systems are used in an engine which has only one exhaust valve and inlet valve per cylinder, then each poppet valve 6 would be controlled on its own by a set of electro-hydraulic control valves comprising a single metering valve 2 individual to the poppet valve 6 and a single switching valve 1 individual to the poppet valve 6.

Whilst above the controlled valves 6 have been inlet and exhaust valves, they could be other types of valve, e. g. exhaust gas recirculation control valves or other gas exchange valves.

The present invention provides complete control over the position of an engine valve. This is done by using closed loop position feedback. By providing a feedback signal the system can take account of imperfections and the component parts do not have to be manufactured to high tolerances.

If combined metering valves and actuators such as described in UK Patent Application No. 0100632.9 are employed then control is enhanced because the bulk modulus of the fluid in the variable volume chamber and the pipe connecting the variable volume chamber to the metering valve is reduced to a minimum. This reduces hysteresis losses and gives more exact control.

Ansprüche

CLAIMS

1. A valve actuating system which opens and closes
an engine valve of an internal combustion engine, the system comprising: a hydraulic actuator connected to the engine valve which comprises a piston sliding in a cylinder and defining with the cylinder a variable volume chamber; a source of pressurised hydraulic fluid; an exhaust for hydraulic fluid; a switching valve connected to both of the source of pressurised hydraulic fluid and the exhaust for hydraulic fluid; and a metering valve connected between the switching valve and the hydraulic actuator; wherein: the switching valve controls direction of flow of hydraulic fluid to and from the hydraulic actuator without controlling rate of flow of fluid therethrough and thereby controls whether the engine valve is opened or closed by the hydraulic actuator ; and the metering valve controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston and hence speed of motion of the engine valve.

2. A valve actuating system which opens and closes a pair of engine valves of an internal combustion engine, the system comprising: a pair of hydraulic actuators connected one each to the pair of engine valves, each hydraulic actuator comprising a piston sliding in a cylinder and defining with the cylinder a variable volume chamber; a source of pressurised hydraulic fluid; an exhaust for hydraulic fluid; a switching valve connected to both of the source of pressurised fluid and the exhaust for hydraulic
fluid; and a pair of metering valves connected one each to the pair of hydraulic actuators, the metering valves connecting the switching valve with the pair of hydraulic actuators; wherein: the switching valve controls direction of flow of hydraulic fluid to and from the pair of hydraulic actuators without controlling rate of flow of fluid therethrough and thereby controls whether the pair of engine valves are opened or closed by the hydraulic actuators; and each metering valve controls rate of flow of hydraulic fluid therethrough without controlling flow direction and thereby controls speed of motion of the piston of the hydraulic actuator connected thereto and hence speed of motion of the engine valve connected to the piston.

3. A valve actuating system as claimed in claim 1 or claim 2 wherein each engine valve has only two operating conditions: a first operating condition in which the switching valve connects the source of pressurised fluid to each hydraulic actuator connected to the switching valve via the metering valve (s), whereby pressurised fluid can be supplied to the variable volume chamber of each hydraulic actuator to cause the piston thereof to move to open the engine valve; and a second operating condition in which the switching valve connects the exhaust for hydraulic fluid to each hydraulic actuator connected to the switching valve via the metering valve (s), whereby hydraulic fluid can be exhausted from the variable volume chamber of each hydraulic actuator and the piston allowed to move to close the engine valve.

4. A valve actuating system as claimed in any one of
the preceding claims, wherein each engine valve is an intake valve controlling the induction of a charge of air or fuel/air mixture into a combustion chamber of the internal combustion engine.

5. A valve actuating system as claimed in any one of claims 1 to 3 wherein each engine valve is an exhaust valve controlling the exhaust of combusted gases from a combustion chamber of the internal combustion engine.

6. A valve actuating system as claimed in any one of the preceding claims wherein the switching valve is a three port, two-way, digital switching valve.

7. A valve actuating system as claimed in any one of the preceding claims in which each metering valve can stop flow of hydraulic fluid therethrough and thereby stop motion of the piston of the hydraulic actuator connected thereto.

8. A valve actuating system as claimed in any one of the preceding claims wherein the switching valve is an electrically controlled valve; each metering valve is an electrically controlled valve; a transducer is associated with each hydraulic actuator and produces for the actuator an electrical signal indicating position of the piston relative to the cylinder; and an electronic controller controls operation of the switching valve and operation of each metering valve and uses the signal (s) produced by the transducer (s) as feedback in a closed loop control arrangement.

9. A valve actuating system as claimed in any one of the preceding claims wherein each hydraulic actuator comprises only one variable volume chamber for hydraulic fluid and spring means which acts on each piston to bias the piston to move to reduce in volume the variable volume chamber defined in part by the piston.

10. An internal combustion engine comprising a valve actuating system as claimed in any one of the preceding claims.

11. A valve actuating system substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

FIG. 1.

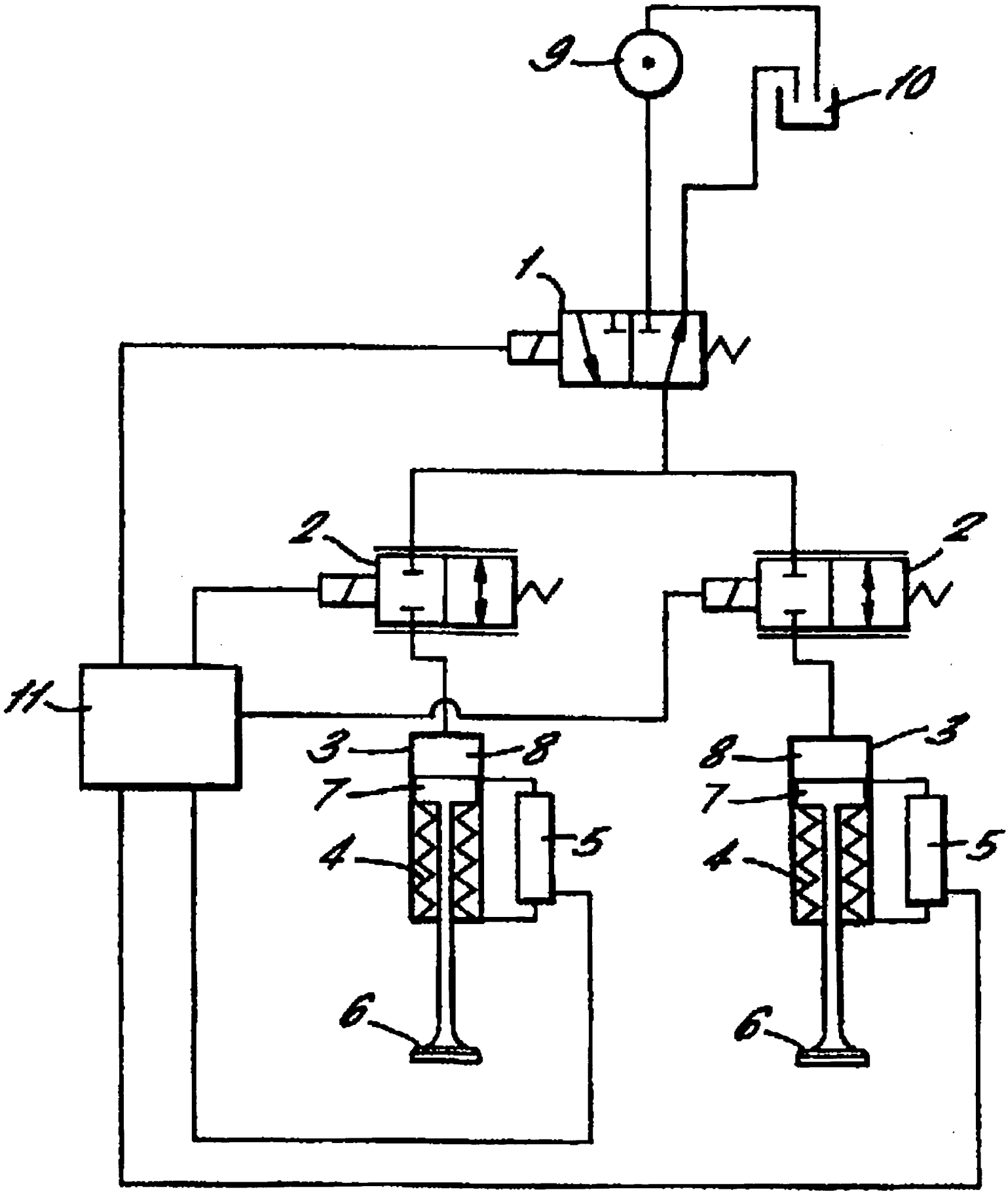

FIG. 1.

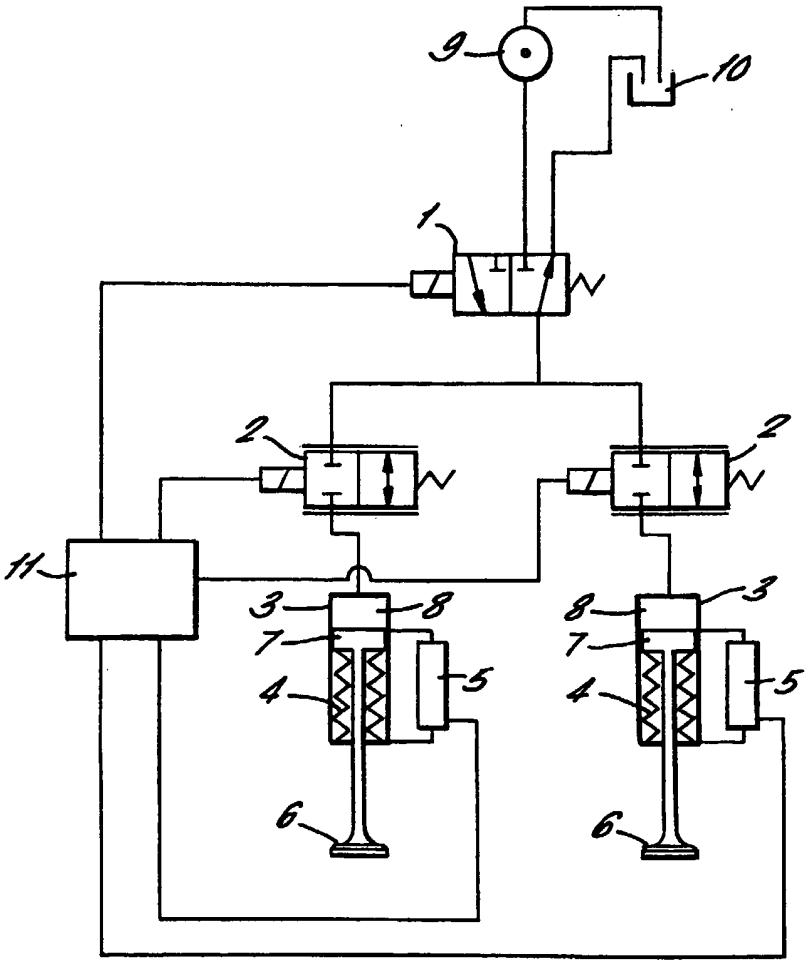

FIG. 2.